How difficult it would be to detect Cosmic Neutrino Background ?

Petr Vogel, Caltech

LBL, June 25, 2009

Based on the paper with Rimas Lazauskas and Cristina Volpe in J. Phys. G. **38**, 025001 (2008).

Outline:

1) Number density of the Cosmic Neutrino Background
2) Clustering of CNB
3) Using coherence (or not)
4) Detection with radioactive targets

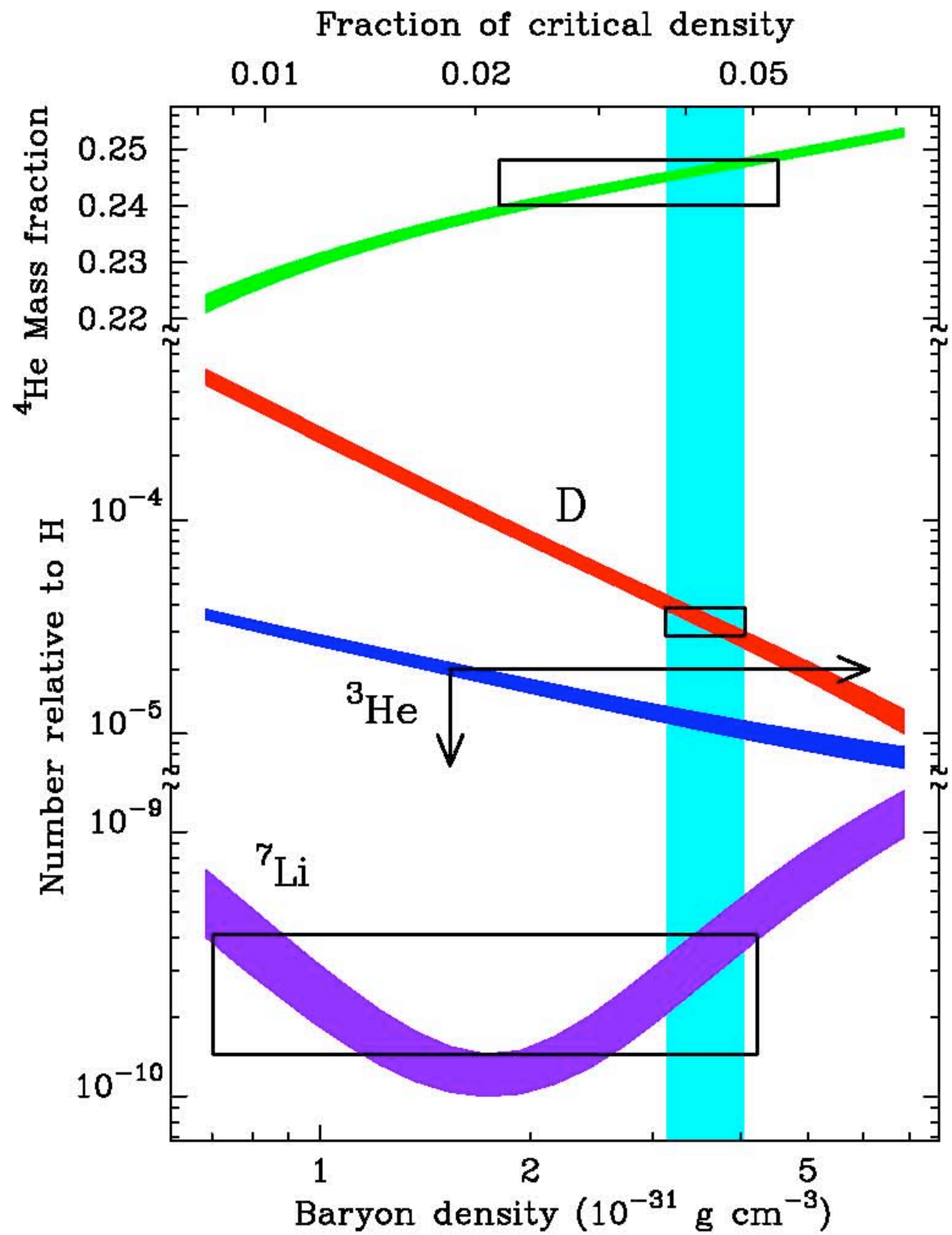
Hot Big-Bang Cosmology
(concordance model of cosmology)

explains everything we know about the evolution of the Universe since early times with remarkable accuracy.

In particular, two totally independent ways of determining the baryon average density (or the ratio of baryons to photons), one from the **Big-Bang Nucleosynthesis** (first few minutes), and the other one from analysis of the temperature fluctuations of the **Cosmic Microwave Background** (~400 ky) agree very well.

Both sets of data also agree (albeit with large error bars) on the prediction that <u>relativistic neutrinos of ~3 flavors</u> were present at those epochs. Since these neutrinos have not interacted since that time with anything, they should be around us until now.

BBN – Predicted Primordial Abundances



D, ^{3}He, ^{7}Li are BARYOMETERS

BBN probes the Universe at ~20 minutes (time when deuteron density reaches its final value)

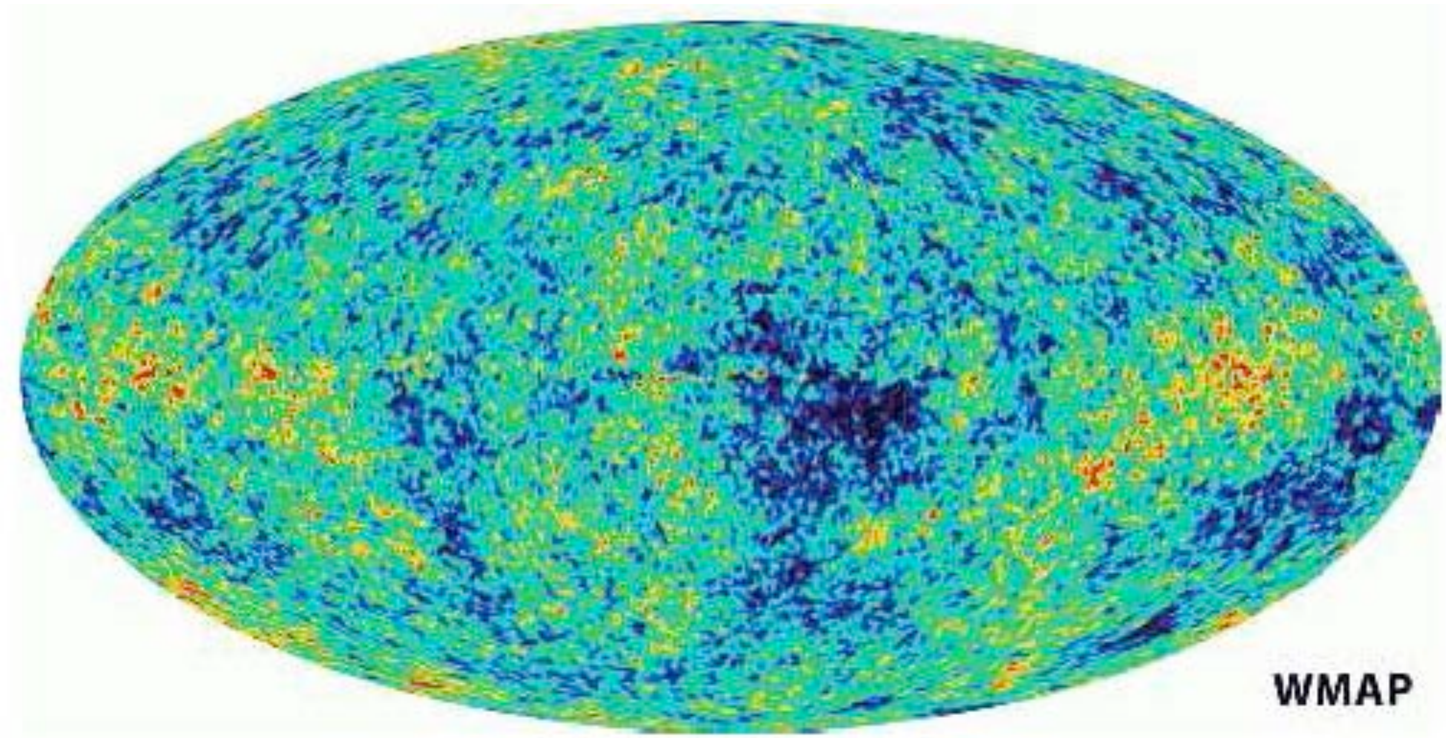
$\rho_B^{BBN} = 3.8 \pm 0.2 \times 10^{-31}$ g cm^{-3}
(Freedman & Turner, 2003)

$N_\nu = 2.4 \pm 0.4$ (from D,^{4}He)
(Steigman 2008)

Note that 3.8×10^{-31}g/cm^3 is the same as $n_B = 2.2\times10^{-7}$ nucleons/cm^3, which in turn is the same as $n_B/n\gamma$ = 6×10^{-10} , the usual value.

CMB temperature fluctuations from WMAP

(snapshot at 380 k years)



Analysis gives $\rho_B^{CMB} = 4.0 \pm 0.6 \times 10^{-31}$ g cm^{-3}
(Freedman & Turner, 2003)

$N_\nu = 3.1_{-1.7}^{+2.2}$ (Steigman 2008, uses also LSS data)

In the radiation dominated epoch energy density and time evolve as

$\rho = 3c^2/(32\pi G_N)\, t^{-2}$; $kT = [45\hbar^3 c^5/(32\pi^3 G_N g_s^*)]^{1/4}\, t^{-1/2}$,
$kT/MeV \sim (t/s)^{-1/2}$

Where $g_s^* = 1 + 7/4 + 3x7/8$ (photons,electrons,3 neutrino flavors)

Neutrinos **decouple** when the expansion rate exceeds the interaction rate:

$\sigma \sim G_F^2\,(kT)^2$, $n_\nu \sim (kT)^3$, $t_\nu = (n_\nu \sigma v)^{-1} \sim G_F^{-2}\,(kT)^{-5}$

$t_{expansion} \sim G_N^{-1/2}\,(kT)^{-2}$

(t_ν - interval between weak interactions, t_{exp} - characteristic expansion time)

From $t_\nu = t_{exp}$ ➡ $kT \sim 1$ MeV, $t_{decoupling} \sim 1$ second

(detailed calculations give $kT(\nu_e) \sim 2$ MeV, $kT(\nu_\mu, \nu_\tau) \sim 3$ MeV), While in equilibrium the number density of each Majorana neutrino flavor is proportional to the photon number density

$$n_\nu/n_\gamma = 3/4 \quad \text{(for relativistic Fermi and Bose gases)}$$

At t ~ 10 s , e^+ and e^- annihilate increasing n_γ.

That process conserves entropy, $s \sim \rho/T$

Thus the photon density n_γ increases by the factor $(1 + 2\text{x}7/8) = 11/4$

$n_\nu = (4/11)(3/4)\, n_\gamma \sim 112$ neutrinos of each Majorana flavor /cm^3

and **$T_\nu/T_\gamma = (4/11)^{1/3} = 0.71$; $T_\nu = 1.94$ K $= 1.67\text{x}10^{-4}$ eV**

Reminder: Few textbook formulas re distribution functions of particle momenta in thermal equilibrium

$$f_i^{eq}(p,T) = \left[\exp\left(\frac{E_i-\mu_i}{T}\right) \mp 1\right]^{-1}$$

		relativistic Bose-Einstein	relativistic Fermi-Dirac	nonrelativistic
number density	n	$\frac{\zeta(3)}{\pi^2} g T^3$	$\frac{3}{4}\frac{\zeta(3)}{\pi^2} g T^3$	$g\left(\frac{mT}{2\pi}\right)^{3/2} e^{-m/T}$
energy density	ρ	$\frac{\pi^2}{30} g T^4$	$\frac{7}{8}\frac{\pi^2}{30} g T^4$	mn
pressure	p	$\frac{\rho}{3}$		$nT \ll \rho$
mean energy	$\langle E\rangle$	$2{,}701 T$	$3{,}151 T$	$m + \frac{3}{2}T$

$$n = g_i \int \frac{d^2\vec{p}}{(2\pi)^3}\ f_i(p,T) \qquad \rho = g_i \int \frac{d^2\vec{p}}{(2\pi)^3}\ E_i\ f_i(p,T)$$

$$p = g_i \int \frac{d^2\vec{p}}{(2\pi)^3}\ \frac{p^2}{3E_i} f_i(p,T) \qquad \langle E\rangle = \rho/n$$

These are then firm predictions of the Hot Big-Bang Cosmology:

Neutrino number density = 112 neutrinos/cm^3 for each flavor, i.e., **56 neutrinos and 56 antineutrinos of each flavor**

Neutrino temperature = 1.94 K = 1.67×10^{-4} eV

If one could confirm (or find deviations) from these predictions, one would test the theory at t ~ 1 sec, T ~ 1 MeV, much earlier and hotter than the tests based on BBN and CMB.

In order to motivate the need for CNB detection even more, lets compare the time, temperature, and redshift of different epochs:

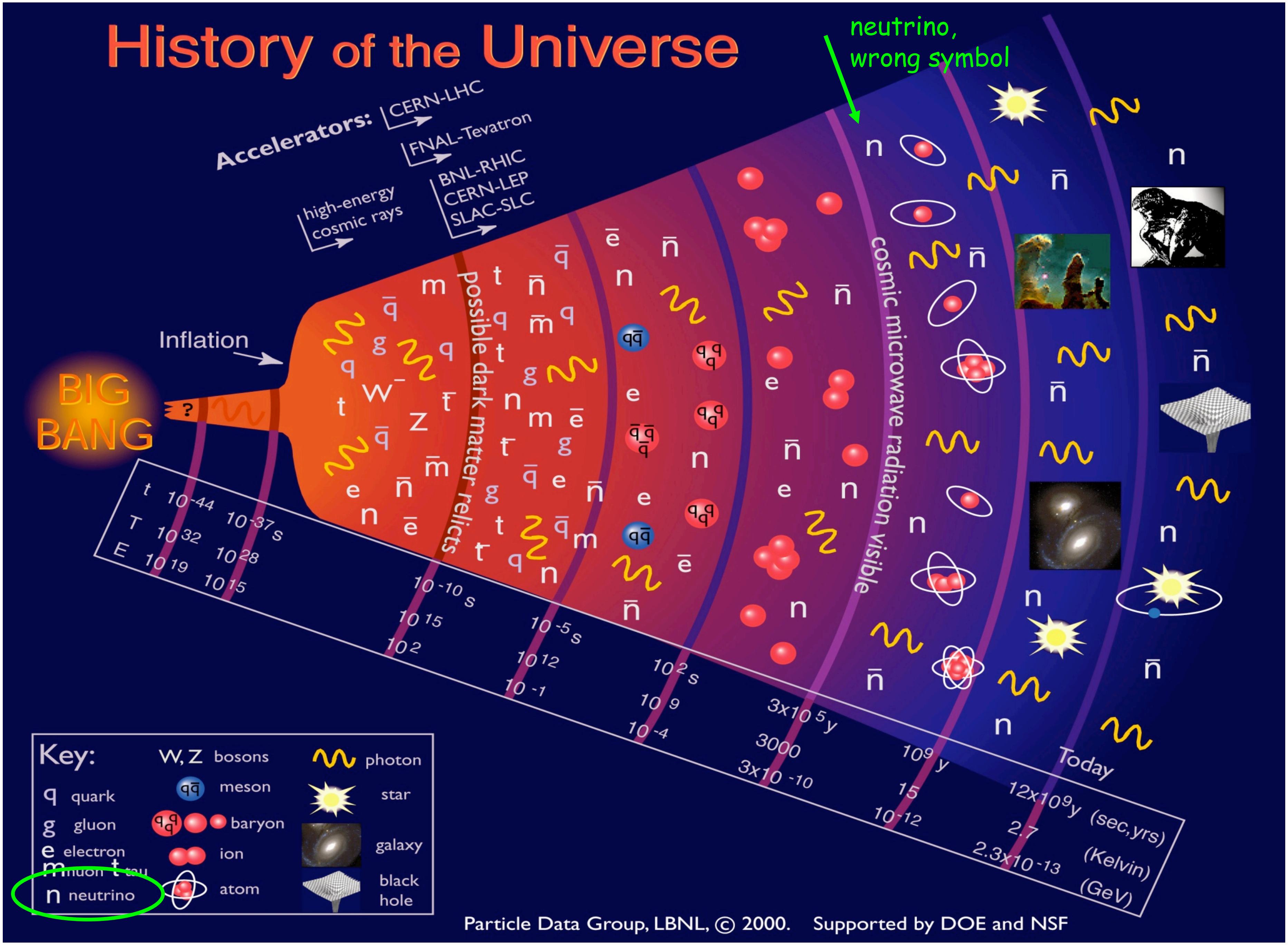
Epoch	time	Temperature	z
CMB	3.8×10^5y	0.26 eV	1100
BBN	100-1000s	0.115-0.036MeV	$(4.9-1.8) \times 10^8$
CNB	~0.18s	~2 MeV	$\sim 1.2 \times 10^{10}$

In other words, by observing CNB we would extend our observational capabilities by almost two orders of magnitude in in temperature and redshift and by almost four orders of magnitude by time since Big Bang.

Note also that the furthest galaxy we see has z~7.

Thus evidence for CNB existence is so far indirect, based only on cosmological arguments and measurements, i.e., on the analysis of big bang nucleosynthesis (few minutes) and on the spectrum of CMB anisotropies combined with the large scale matter mower spectrum (400k years).

We would like to have more direct evidence, based on the weak interactions of CNB, and sensitive to the CNB in the present epoch and in our local neighborhood.


History of the Universe
neutrino,
wrong symbol
Accelerators:
CERN-LHC
FNAL-Tevatron
BNL-RHIC
CERN-LEP
SLAC-SLC
high-energy
cosmic rays
Inflation
BIG
BANG
possible dark matter relics
cosmic microwave radiation visible
t 10 -44 10 -37 s 10 -10 s 10 -5 s 10 2 s 3x10 5 y 10 9 y 12x10 9 y (sec,yrs)
T 10 32 10 28 10 15 10 12 10 9 3000 15 2.7 (Kelvin)
E 10 19 10 15 10 2 10 -1 10 -4 3x10 -10 10 -12 2.3x10 -13 (GeV)
Today
Key:
W, Z bosons
q quark
g gluon
e electron
m muon
t tau
n neutrino
meson
baryon
ion
atom
photon
star
galaxy
black hole
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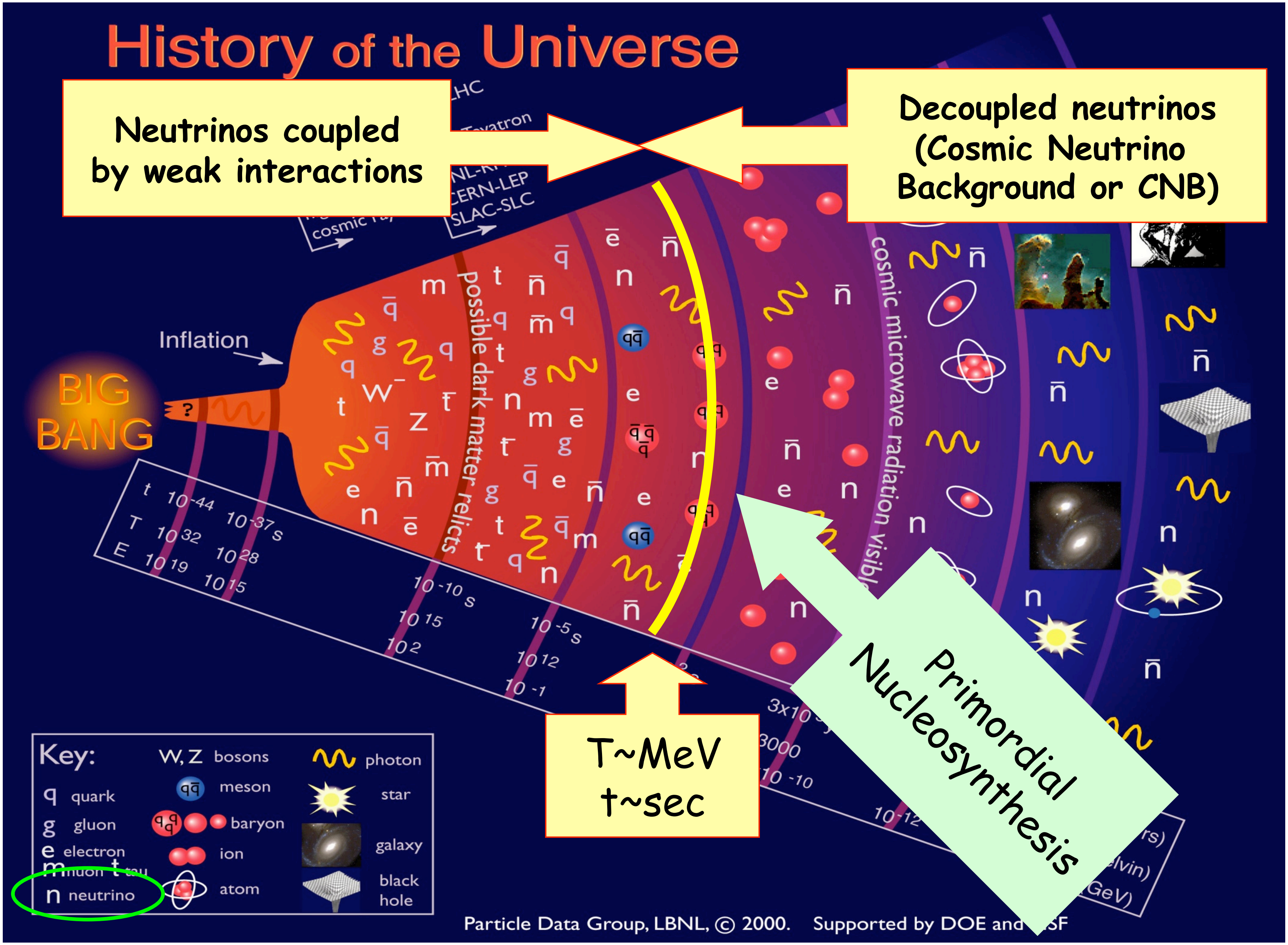
History of the Universe
Neutrinos coupled by weak interactions
Decoupled neutrinos (Cosmic Neutrino Background or CNB)
BIG BANG
Inflation
possible dark matter relicts
cosmic microwave radiation visible
T~MeV
t~sec
Primordial Nucleosynthesis
LHC
CERN-LEP
SLAC-SLC
Key:
q quark
g gluon
e electron
n neutrino
W, Z bosons
meson
baryon
ion
atom
photon
star
galaxy
black hole
Particle Data Group, LBNL, © 2000.
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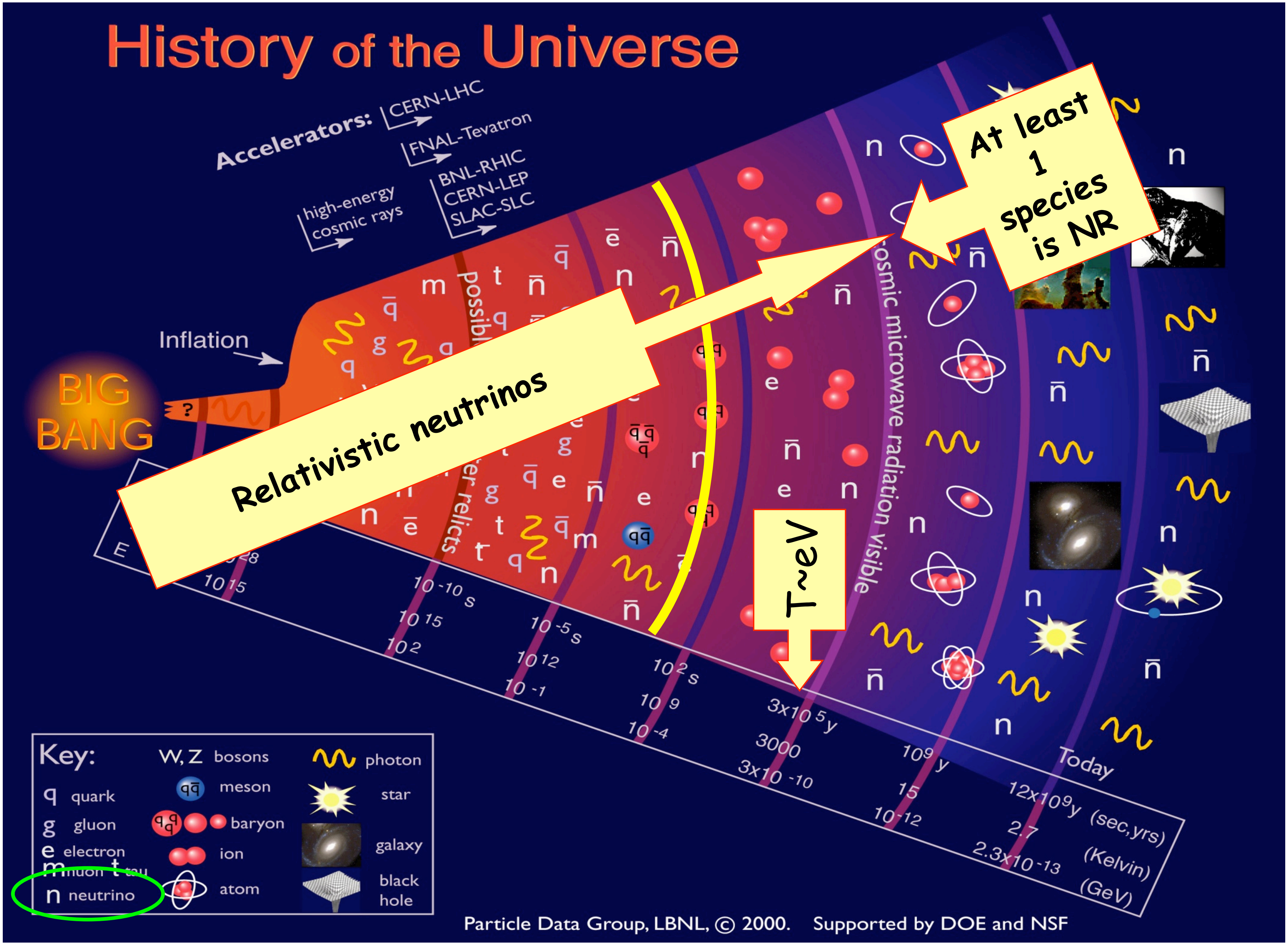
History of the Universe
Accelerators:
CERN-LHC
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high-energy cosmic rays
Inflation
BIG BANG
Relativistic neutrinos
At least 1 species is NR
T~eV
cosmic microwave radiation visible
possible super relics
10 -10 s
10 15
10 2
10 -5 s
10 12
10 -1
10 2 s
10 9
10 -4
3x10 5 y
3000
3x10 -10
10 9 y
15
10 -12
Today
12x10 9 y (sec,yrs)
2.7 (Kelvin)
2.3x10 -13 (GeV)
Key:
W, Z bosons
photon
q quark
meson
star
g gluon
baryon
galaxy
e electron
ion
m muon t tau
n neutrino
atom
black hole
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Clustering neutrino density enhancement

Massive particles become nonrelativistic when their mass exceeds the temperature of the Universe. From than on they can become bound, i.e., concentrate in structures of various sizes. Their densities in these structures can far exceed the average density derived from cosmological measurements and arguments.

The overall energy density (critical density for $\Omega = 1$) of the Universe is

$$\rho_c = 1.05\text{x}10^4\, h_{100}^2\ \text{eV/cm}^3 \sim 5\ \text{keV/cm}^3\ (\text{since } h_{100} \sim 0.73)$$

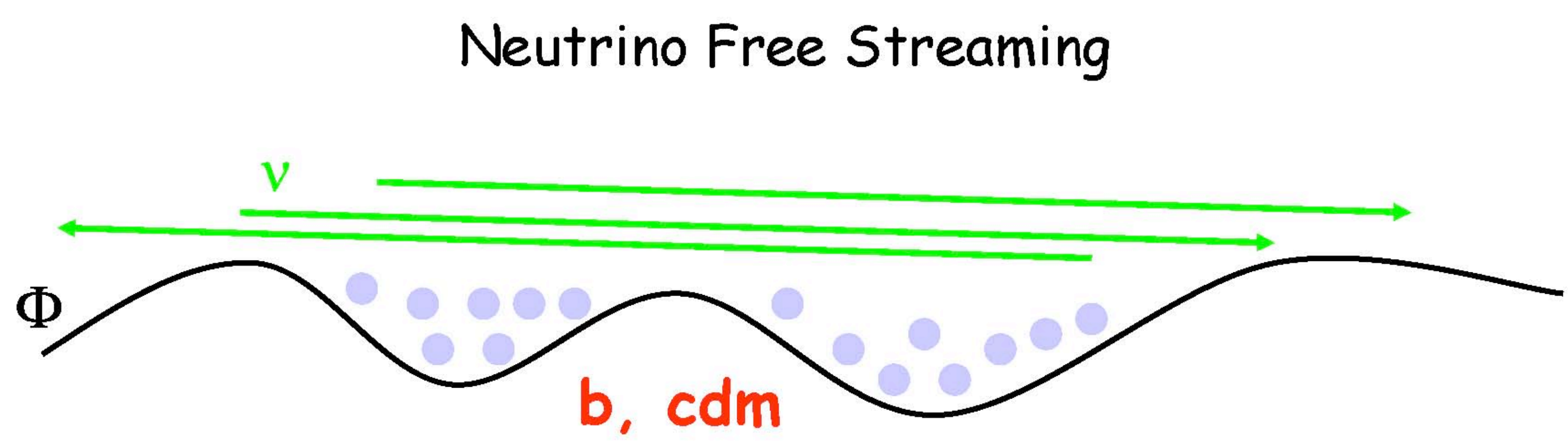
component	average ρ(keV/cm^3)	Structure	Enhancement
baryons	0.2	galaxy(disk)	$\sim 5\text{x}10^6$
dark matter	1.0	galaxy(halo)	$\sim 3\text{x}10^5$
Neutrinos	**112(Σm_ν/keV)**	**clusters**	**~100**

I assumed that neutrinos will concentrate in **clusters of ~ 5 Mpc** size with the total mass of ~10^{15} $M_\odot$ and that their enhancement in them will be similar to the average enhancement of baryons and cold dark matter.

Note that $\Omega_\nu/\Omega_{baryon}$ **~ 112 (m_ν/eV) / 200 eV ~ 0.5 (m_ν/eV)** for each flavor. I assumed that this ratio remains fixed in the structures where both neutrinos and baryons cluster.

Note also, that the energy density, and naturally also the number density of neutrinos scales as R^{-3}, where R is the characteristic size of of the clustering region

Neutrinos are natural Hot Dark Matter (HDM)candidates



An alternative estimate of the enhancement $n_\nu/\langle n_\nu\rangle$ is obtained by considering the HDM clustering with a velocity dispersion *v* (Peebles):

$$n_\nu/\langle n_\nu\rangle \approx v^3\, m_\nu^{\,3}/(2\pi)^{3/2} = 330\ (v/500\ \mathrm{km/s})^3\ (m_\nu/\mathrm{eV})^3$$

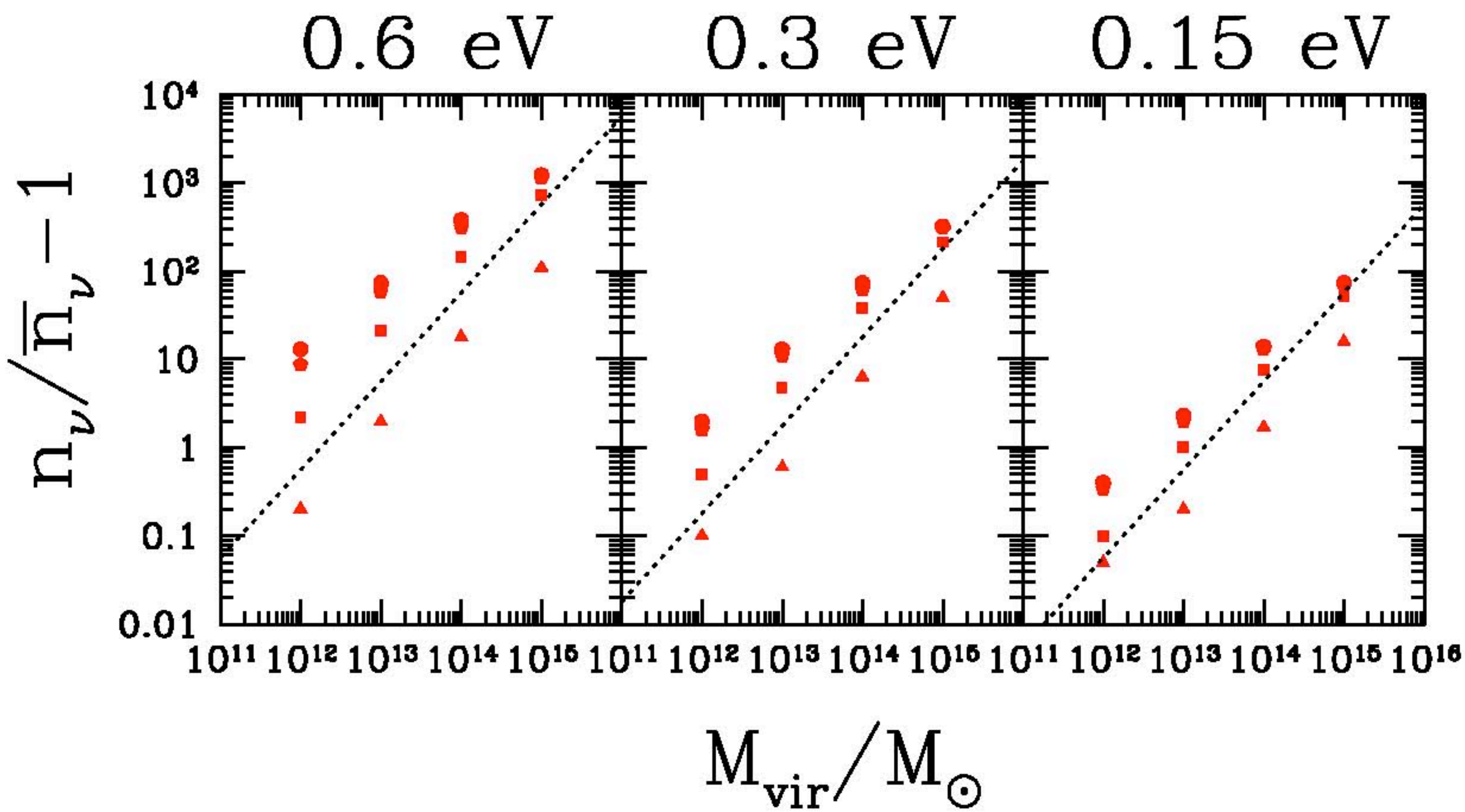
Obtained for $\langle n_\nu\rangle = 110\ \mathrm{cm}^{-3}$ neutrino average number density.

Thus this estimate agrees with our previous $n_\nu/\langle n_\nu\rangle \approx 100$
(as far as the order of magnitude is concerned)

Dependence of the overdensity on the mass of the cluster and on the neutrino mass (from Ringwald & Wong, 04)

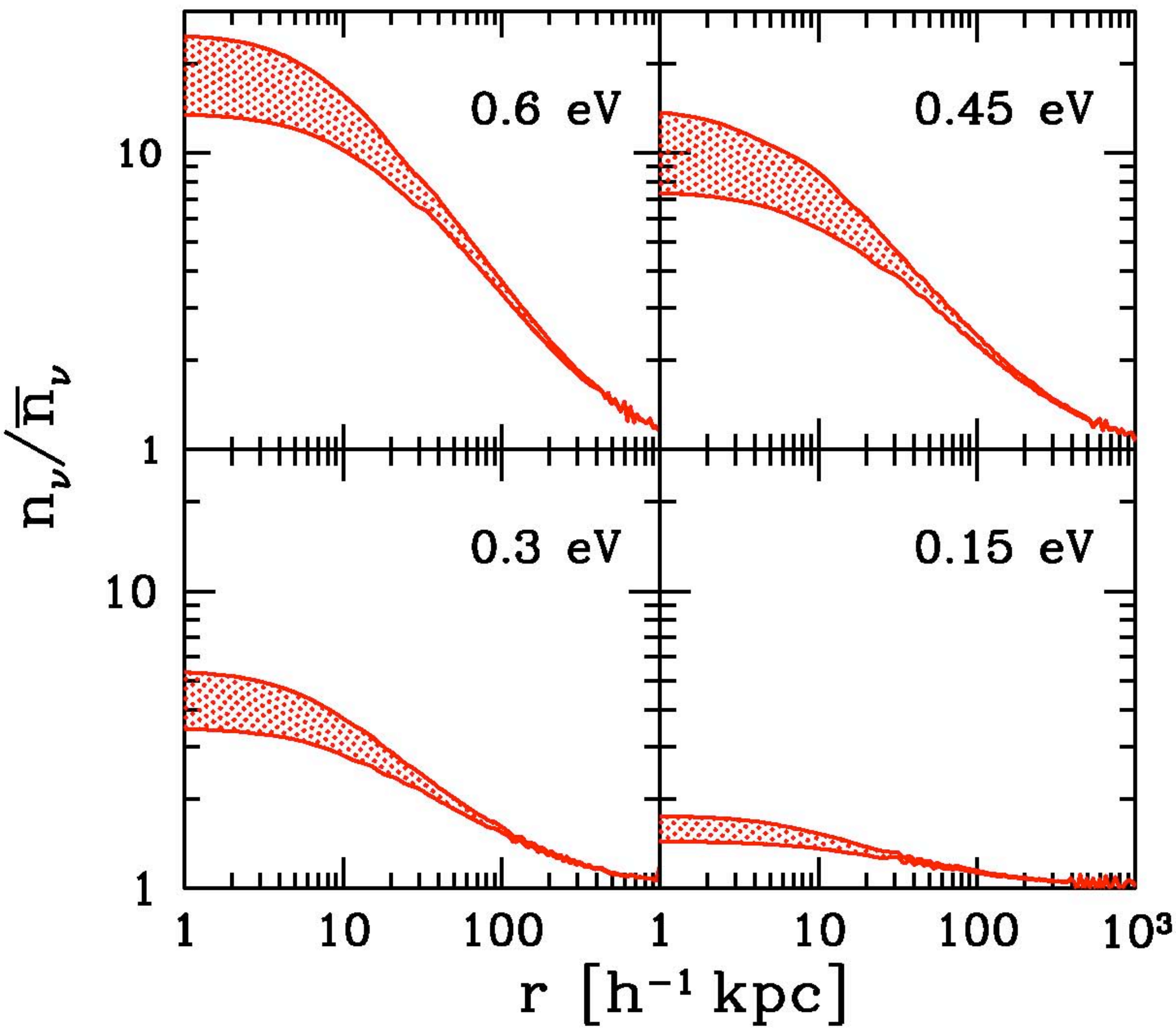
The red symbols indicate different distances from the cluster center,
▲ are for r = 1 Mpc/h.

For $M_{vir} = 10^{15}\,M_\odot$, m_ν > 0.3 eV our estimate $n_\nu/\langle n_\nu\rangle$ = 100 looks OK

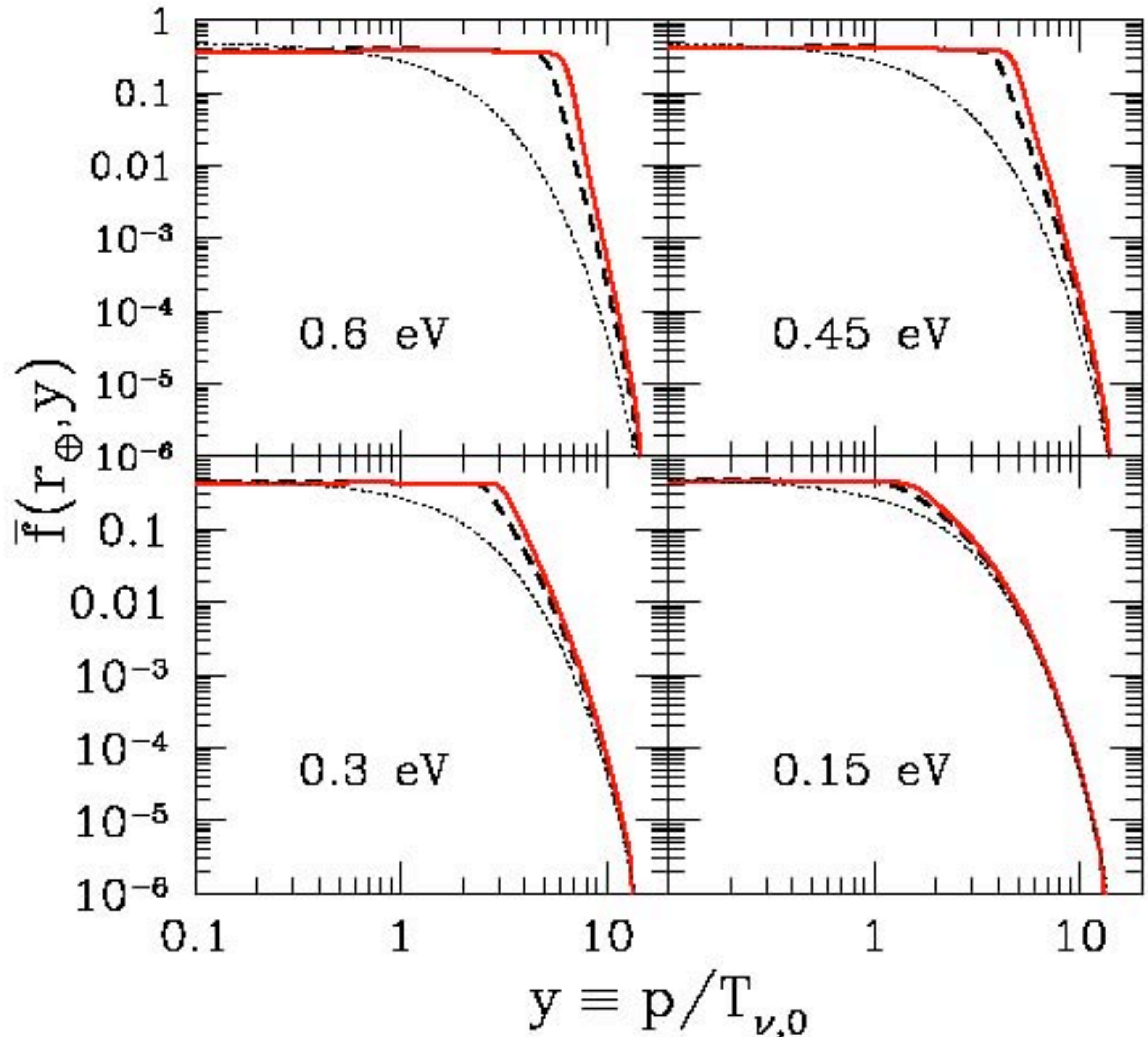


Clustering evaluation for the Milky Way (Ringwald & Wong 04)

At 8 kpc the overdensity is less than what we estimated.



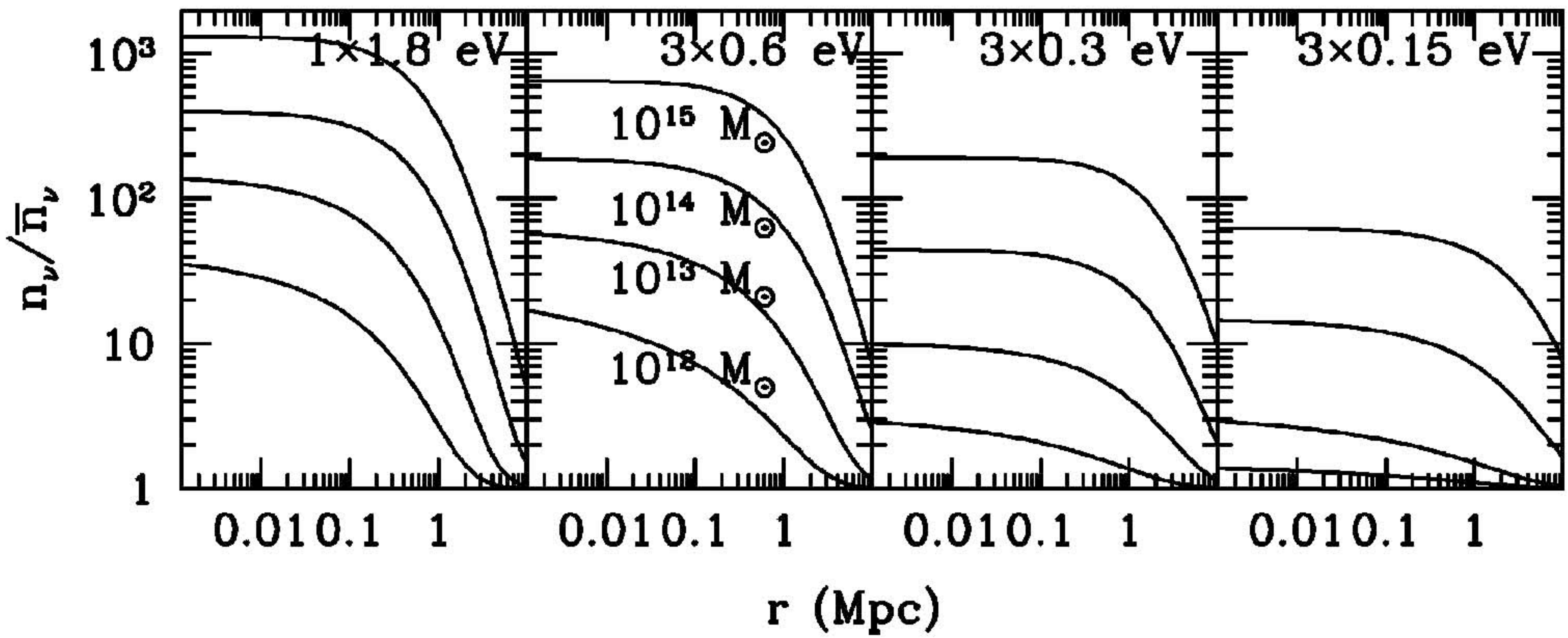
Local and present calculated CNB momentum distribution (Ringwald & Wong, 04) Full and dashed, two assumed distributions in Milky Way, dotted, relativistic Fermi-Dirac distribution. Note the relatively small deviations from F-D.



Neutrino momenta are almost isotropic; the Earth is moving through the CNB sea with $v \sim 10^{-3}c$

Another calculated neutrino clustering magnitudes
(Singh & Ma, Phys. Rev. **D67**, 023506 (2003))

Shown is the dependence on the cluster size and neutrino mass. Here, for heavier neutrinos and larger clusters substantial number density enhancement occurs.



How do we detect Cosmic Neutrino Background (CNB)?

The first idea, from ~1980 when people believed that $m_\nu \sim 30$ eV, was to use the coherent scattering on macroscopic objects.

de Broglie wavelength $\lambda_\nu = h/p_\nu \sim 2.4$ mm (for $p_\nu \sim 3T_\nu$)

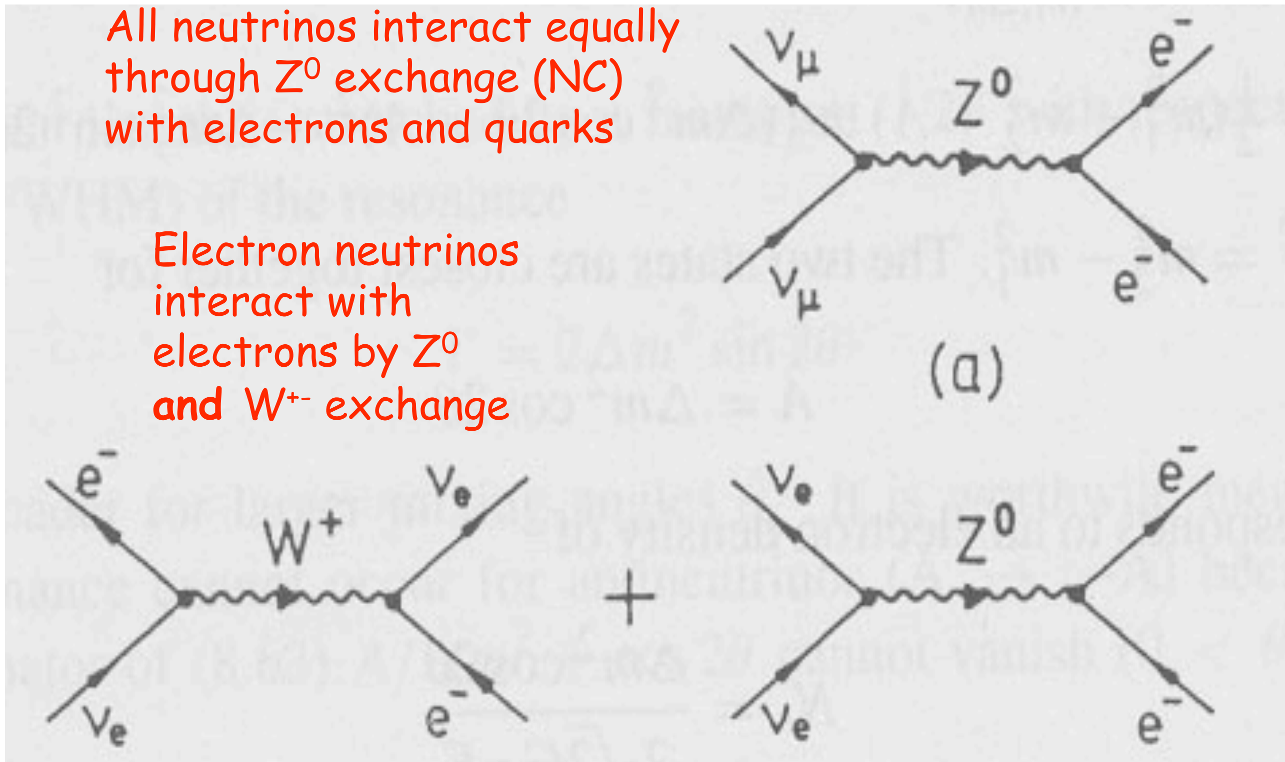
A sphere with $d = \lambda_\nu$ contains $\sim 10^{21}$ nucleons. If neutrinos interact coherently with all of them, it should help a lot.

To describe the reflection or refraction on a thin foil, use the concept of index of refraction

$$n = 1 + N \lambda_\nu^2 f(0)/2\pi,$$

where N is the number of density of target atoms and f(0) is the forward scattering amplitude.

In order to evaluate n-1, the deviation of index of refraction from unity, proceed exactly the same way as in the treatment of the MSW effect for matter neutrino oscillations, namely evaluate these graphs:



Thus $n-1 = \pm [G_F N (3Z - A)]/(2^{3/2} T_\nu)$ for ν_e ($\bar{\nu}_e$)

$n-1 = \pm [G_F N (Z - A))]/(2^{3/2} T_\nu)$ for ν_μ, ν_τ ($\bar{\nu}_\mu, \bar{\nu}_\tau$)

where T_ν is the kinetic energy of nonrelativistic neutrinos

For ν_μ on gold **$1-n \approx 10^{-7}$ (eV/m_ν)** for v_ν = 500 km/s
and the critical scattering angle **$\theta_c = [2(1-n)]^{1/2} \approx 1.5$ arcmin**

Consider neutrinos with flux density **j (neutrinos/sr cm^2 sec)**.
Collision rate for area of 1 cm^2 with angles less than θ_c is
$2\pi j\ \theta_c$ and the momentum transfer is **$p_\nu \theta_c$**

The **pressure** of the `neutrino wind' is then

$$dp/dt = 4\pi\ \rho_\nu N\ G_F (A-Z)\ /2^{1/2}$$

linear in G_F and independent of v_ν (Opher,74,82; Lewis,80)

Unfortunately, this derivation is wrong !!!

Arguments against the effects linear in G_F:

(Cabibbo & Maiani, 82; Langacker,Leveille & Sheiman, 83)

1) Another factor θ_c, projection of the area orthogonal to the neutrino ray is missing from dp/dt, thus **$dp/dt \sim G_F^{3/2}$**.

2) <u>More importantly</u>, the scattered wave penetrates into the foil and decays exponentially with **$z_0 \approx \lambda/2\pi\,\theta_c$**.

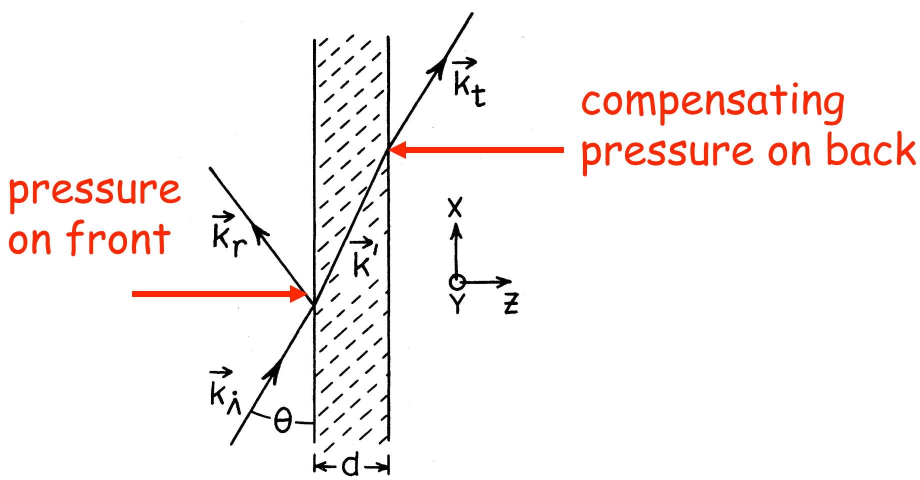
   Thus, the pressure dp/dt vanishes if the foil thickness d is

   $$d << \lambda/\theta_c$$

   However, in our above example,

   $$\lambda/\theta_c \approx 8 \text{ meters} \times (m_\nu/eV)^{1/2}$$

   Thus the pressure on the opposite surfaces of the foil cancel. The only effect left is $\sim G_F^2$.



Another proposal to use coherence, this time $\sim G_F^2$
(Shvartsman,Braginski,Gershtein,Zeldovich, and Khlopov, 82)

Scatter relic neutrinos on spheres with **$r = \lambda$** ; use the virial motion of Earth with respect to the relic neutrinos, **$v \sim 300$km/s** and measure the force on such spheres.

Cross section **$\sigma = G_F^2\, m_\nu^2\, k_L^2/\pi$** , $k_L = 3Z-A$ (for ν_e), $A-Z$ (for ν_μ,ν_τ)

Force **$F = 2n_\nu v\, m_\nu v\, \sigma\, N_A$**
(n_ν = density of relic neutrinos, N_A = number of target atoms in each sphere)

Acceleration of each sphere **$a = F/m_{sphere}$** is independent of m_ν.

Take **iron** spheres, assume clustering **$n_\nu/\langle n_\nu\rangle = 100$,**

$a \sim 3 \times 10^{-26}$ cm s^{-2}, $F \sim 3 \times 10^{-30}$ dyne
This is ~13 orders of magnitude from the sensitivity of the current Dicke - Eotvos type experiments.

Even though proposals for a substantial improvement of the sensitivity to small accelerations exist, they were never demonstrated.

Moreover, for Majorana neutrinos there is a further suppression of the acceleration by

$(v/c)^2 \sim 10^{-6}$ for unpolarized targets,

$(v/c) \sim 10^{-3}$ for polarized targets

(see Hagmann, astro-ph/9902102)

Since none of these proposals work, by a huge margin, lets consider the usual way of detecting neutrinos, by <u>charged current weak interactions</u>.

The problems to solve:

1) **Can one find an appropriate target?**
2) **How many target atoms can one use in practice?**
3) **What is the cross section, and is the event rate sufficient?**
4) **Can one separate the signal from background?**

Each of these items is challenging, but it turns out that the needed technological improvements are ***only(??!!)*** one or few orders of magnitude each, so it is worthwhile to consider them in more detail.

Consider first the fluxes and corresponding (kinetic) energies (for each neutrino flavor):

	Average	With clustering (v=500kms^{-1})
Flux (cm^{-2} s^{-1})	0.8×10^{9} x (eV/m_ν)	2.8×10^{11}
Kin. energy(eV)	1.2×10^{-7} x (eV/m_ν)	1.4×10^{-6} (m_ν/eV)

These fluxes can be compared to the solar pp neutrino flux of ~6×10^{10}/cm^2 s, distributed over 420 keV, or to the ν_e flux at a distance of 1 km from a power reactor, 4×10^{9}/cm^2 s spread over several MeV.

So, at the very small, sub eV, energies the CNB flux dominates over any other neutrino fluxes by a very large factor.

Since the momentum of the CNB $p_\nu \rightarrow 0$, we must consider only exothermic reaction, i.e., reactions on unstable targets.

What is the behavior of the cross section when $p_\nu \rightarrow 0$?

The well known endothermic reaction $\bar{\nu}_e + p \rightarrow e^+ + n$ has threshold (recoil neglected) E_{thr} =

and cross section

$$\boxed{\frac{d\sigma}{d\cos\theta} = \bar{G}^2 E_e p_e [(f^2 + 3g^2) + (f^2 - g^2) v_e v_\nu \cos\theta] \quad \text{with } \bar{G} = G_F \cos\theta_C / \sqrt{2\pi}.}$$

The positron energy is $E_e = E_\nu + E_{thr.}$ Clearly, this will not go if $E_\nu \rightarrow 0$.

What about the exothermic (hypothetical, there are no free neutrons) reaction $\nu_e + n \to e^- + p$ with $E_e = M_n - M_p + E_\nu$ which remains positive and $E_e \geq m_e$ even when $E_\nu \to 0$?

The cross section now contains $\mathbf{1/v_\nu}$, which means that the rate, n

$$\boxed{\frac{d\sigma}{d\cos\theta} = \frac{\bar{G}^2}{v_\nu} E_e p_e [(f^2+3g^2)+(f^2-g^2)v_e v_\nu \cos\theta]}$$

(see Weinberg 62, Cocco,Mangano,Messina 07)

Naturally, the $1/v_\nu$ factor should be there even for the endothermic reactions, but becomes irrelevant since in that case $\mathbf{v_\nu \to c}$ (=1 here). This is a general result for reactions with nonrelativistic projectiles (known long time ago for the case of slow neutrons).

Perhaps the factor $1/v_\nu$ deserves a more detailed explanation:

Standard expression for the cross section on free nucleons at low neutrino energies is

$$\frac{d\sigma}{dq^2} = \frac{G_F^2 \cos^2\theta_C}{\pi} \frac{|\mathcal{M}|^2}{\left(s - M_p^2\right)^2}$$

Where $$|\mathcal{M}|^2 = M_n M_p E_\nu E_e[(f^2+3g^2) + (f^2-g^2)v_e v_\nu \cos\theta],$$

and $$\left(s - M_p^2\right)^2 \to [s-(M_p+m_\nu)^2][s-(M_p-m_\nu)^2] = 4M_p^2 p_\nu^2,$$

while $$\frac{dq^2}{d\cos\theta} = 2p_\nu p_e.$$

And now putting everything together one gets, since $v_\nu = p_\nu/E_\nu$

$$\frac{d\sigma}{d\cos\theta} = \frac{\bar{G}^2}{v_\nu} E_e p_e[(f^2+3g^2) + (f^2-g^2)v_e v_\nu \cos\theta]$$

Consider now reactions on unstable nuclear targets A_Z

$\nu_e + A_Z \to e^- + A_{Z+1}$ or $\bar{\nu}_e + A_Z \to e^+ + A_{Z-1}$

where the allowed $\beta^\pm$ decay of $A_{Z\pm1}$ is characterized by the known nuclear matrix element $|M_{nucl}|^2 \approx 6300/ft_{1/2}$.

The cross section in cm^2 for these exothermic reactions is

$$\sigma = \sigma_0 \times \langle \frac{c}{v_\nu} E_e p_e F(Z, E_e) \rangle \frac{2I' + 1}{2I + 1}$$

with

$$\sigma_0 = \frac{G_F^2 \cos^2 \theta_C {m_e}^2}{\pi} |M_{nucl}|^2 = \frac{2.64 \times 10^{-41}}{ft_{1/2}}$$

When $v_\nu \to 0$ the $e^\pm$ energies are monoenergetic $E_e = Q + m_e + m_\nu$

We can consider now the answer to our first question:

Can one find an appropriate target?

Clearly the unstable A_Z target should have halflife $t_{1/2}$ longer than the duration of the measurement, i.e., **$t_{1/2} \geq$ years**.
It could be manmade, or it could exist in nature. However, natural radioactivity has **$t_{1/2} \geq 10^9$ years**.

The target A_Z should also have minimal possible **$ft_{1/2}$** so that the cross section is as large as possible. This means that the superallowed decays, with **$ft_{1/2} \sim 1000$** are preferred.

Now, lets consider the second question:

How many target atoms can one use in practice?

When reviewing possible targets, the tritium (^3H) clearly comes to mind. Its halflife **$t_{1/2}$ = 12.3 years** is just right, and **$ft_{1/2}$ = 1143** is almost as small as the $ft_{1/2}$ for the free neutron decay.

The technology of production is well developed, and using as much as **1 Mcu (2.1x10^{25} tritium atoms)** is very challenging but appears to be technologically possible.

This corresponds to just ~100 g of pure tritium.
(Note, however, that the Karlsruhe facility, handling all tritium for the KATRIN experiment, as well as for ITER, is licensed for maximum only 20 g of tritium. KATRIN experiment will run with ~3 curies T_2 source, constantly recirculated.)

Alternative target, considered in the literature (Messina) is ^{187}Re.

It has Q_β = 2.4 keV, $T_{1/2}$ = 4.4 x 10^{10} years, $ft_{1/2}$ = 1.6 x 10^{11} ,

Hence one would need ~10^8 times more target material.

Small ^{187}Re detectors with good energy resolution exist (~mg).

If they can be made bigger, say few g at least, and if one could combine many of them, this might be an alternative CNB detection possibility.

Now the third question:

What is the cross section, and the event rate?

To estimate the relic neutrino velocity, lets neglect the virial motion and use $v_\nu/c \sim 3T_\nu/m_\nu$, with $T_\nu = 1.9$ K.

With this assumption $\sigma = 1.5\times10^{-41}\,(m_\nu/\mathrm{eV})\ \mathrm{cm}^2$

The CNB capture rate per tritium atom is independent of m_ν,

$R = \sigma \times v_\nu \times n_\nu \approx 1.8 \times 10^{-32} \times n_\nu/\langle n_\nu\rangle\ \mathrm{s}^{-1}$ (independent of v_ν)

And the number of events is
$N_{\nu\,capt} \approx 830\ \mathrm{yr}^{-1}\ \mathrm{Mcu}^{-1}$ for $n_\nu/\langle n_\nu\rangle = 100$
So, the number of events would be reasonably large.
(this estimate is somewhat larger than in our paper;
I did not use round-off.)

Can we understand that it is possible to have a considerably larger neutrino capture rate with only ~100g of tritium compared with ~500 ton (fiducial) of scintillator in KamLAND?

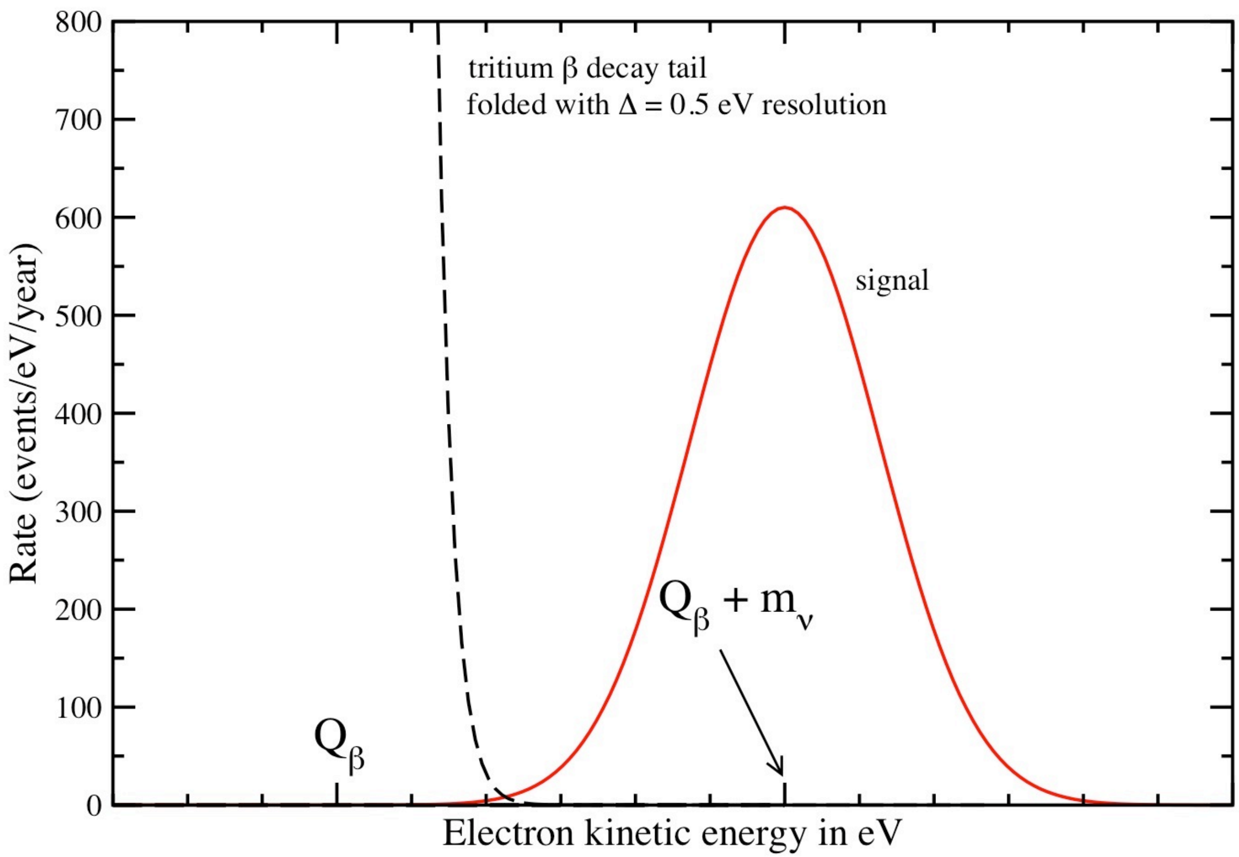
Here are the ratios tritium/KamLAND:

Cross section	~100
Number of targets	$\sim 5\times10^{-7}$
Flux	$\sim 10^{5}$
Total	~5

Finally, the last and most difficult question:

Can one separate the signal from background?

There are 3.7×10^{16} tritium β decays/s , and hence emitted electrons distributed over the energy interval 0 — Q_β - m_ν and smeared by the detector energy resolution. The fraction of electrons in the energy interval of width Δ just below the endpoint is ~ $(\Delta/Q_\beta)^3$



This is for Δ =0.5 eV m_ν=1 eV and $n_\nu/\langle n_\nu\rangle$ = 50.

KATRIN-type spectrometer cannot be made any bigger

There are, thus, two challenging problems:

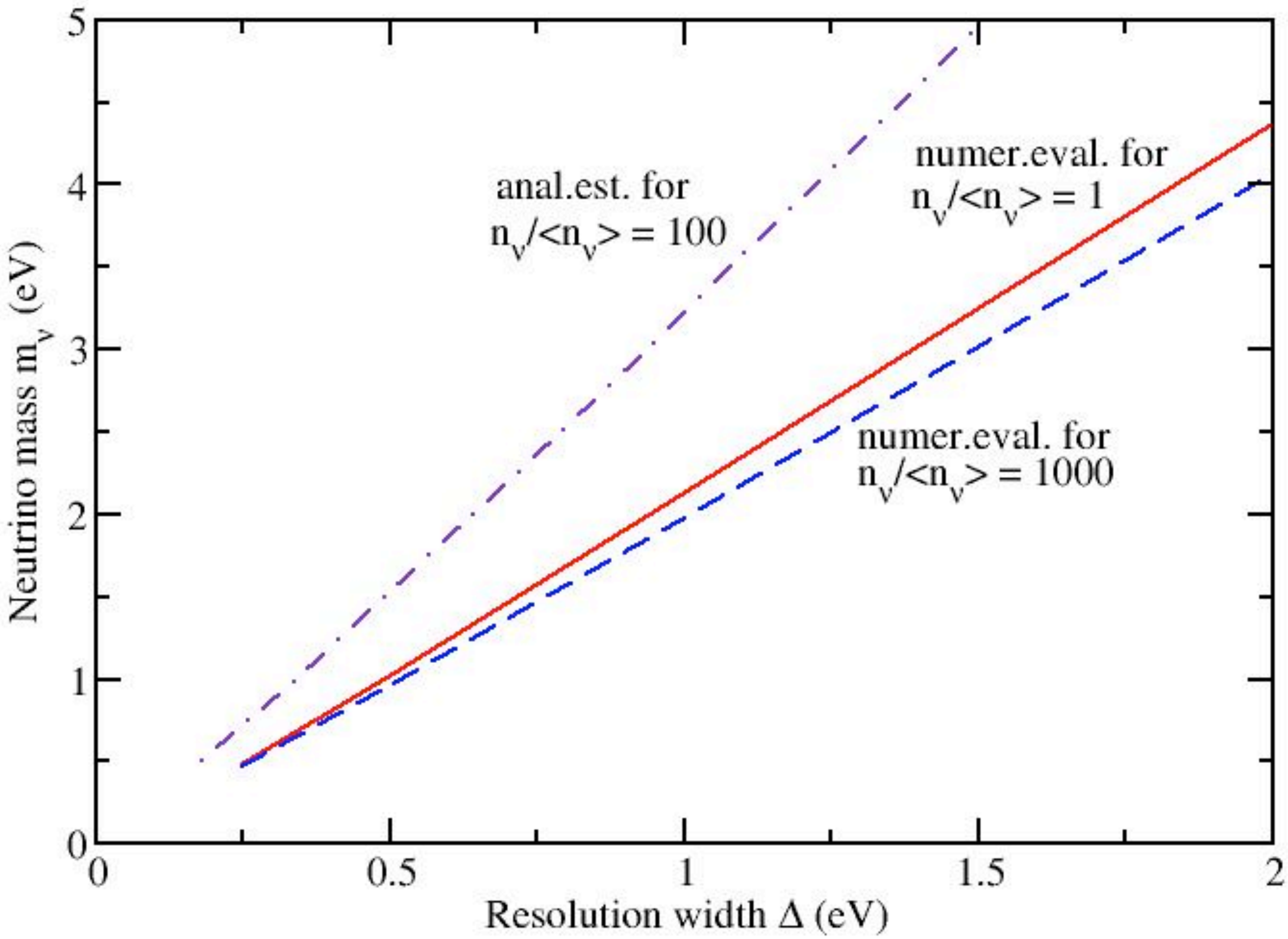
1) Can one filter out up to the ~10^{16} electrons/s that have energies below the endpoint?
   In KATRIN design the ratio between electrons in the window of planned 0.2 eV sensitivity and the total decay rate is ~10^{15}. So, the filter used in KATRIN will be almost capable to reach the required rejection ratio.
2) Can one reach the required energy resolution? And how the signal to background ratio depends on the resolution Δ and on the neutrino mass m_ν?
   It turns out one can make an analytic estimate of the ratio

   $$\lambda_\nu/\lambda_\beta = 6\pi^2 n_\nu/\Delta^3 \times (2\pi)^{1/2} e^{2z} , \quad z = (m_\nu/\Delta)^2$$

   valid reasonably well as long as $m_\nu > \Delta$ (Cocco *et al.*). Note that this ratio is independent on the Q-value and on the β decay nuclear matrix element (hence also on $t_{1/2}$)

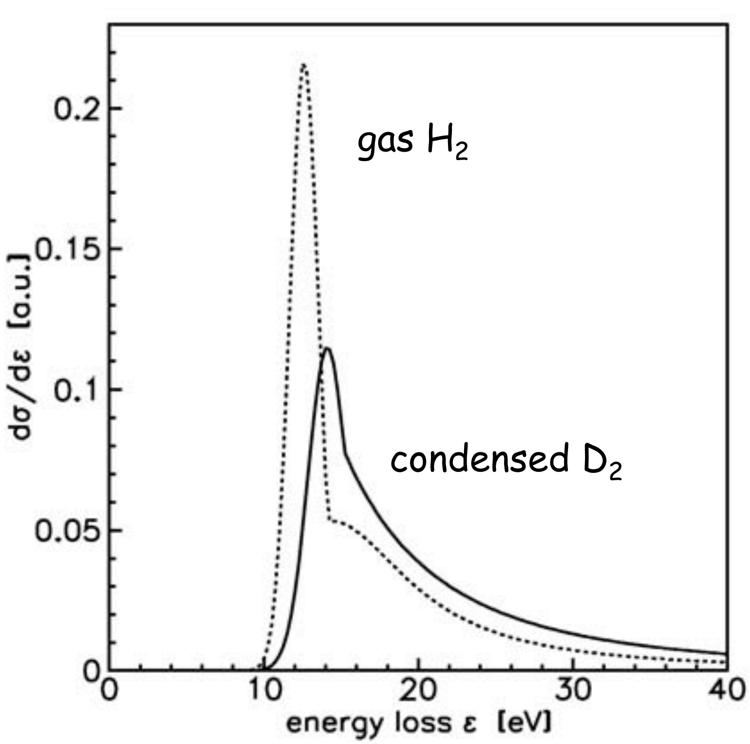
The analytic formula suggest that **$m_\nu/\Delta \sim 3$** is needed, numerical evaluation gives **$m_\nu/\Delta \sim 2$** , a somewhat more favorable ratio.

Relation between m_ν and Δ for which signal/background = 1

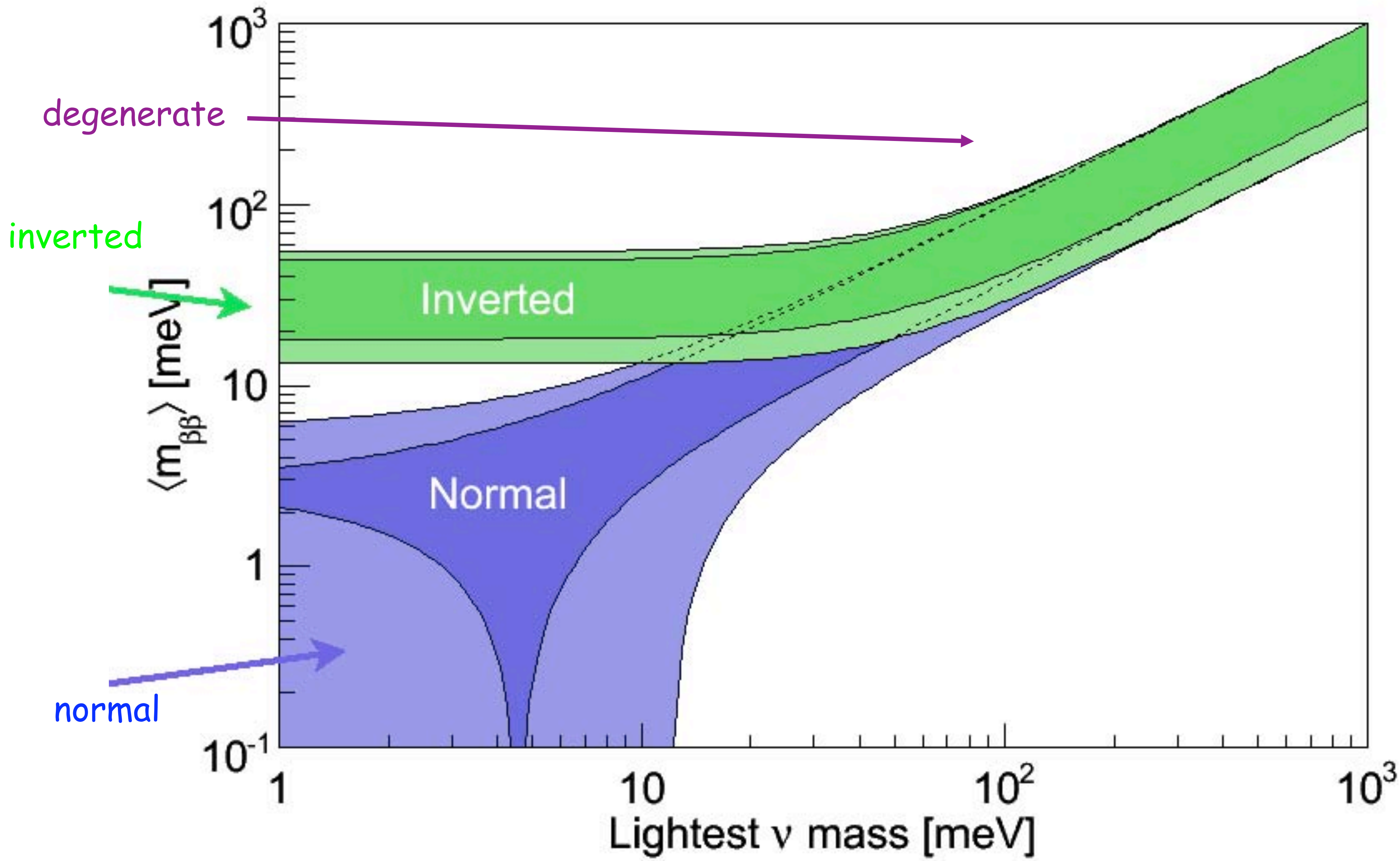


Here are potential killer problems:

1) Past and planned experiments use molecular T_2. The rotational-vibrational states in the final ^{3}HeT molecule are spread over ~0.5 eV. That essentially limits the achievable resolution. However, using atomic T would be very difficult.
3) Electrons scatter on T_2 with $\sigma=3\times10^{-18}$cm^2. This limits the source column density and makes sources of 1kCu or more impossible. New arrangement would be needed for stronger sources (see the idea in Monreal & Formaggio, arXiv:0904.2860).



Representation of the three different possible neutrino mass patterns.
The method of detecting CNB discussed here appears to be very challenging,
but with effort applicable for the case of degenerate mass pattern



Summary

1) We have discussed the challenges of detecting the primordial neutrinos (in particular the ν_e component) using the neutrino capture on radioactive nuclei, with emphasis on tritium as target.
2) Among the various technological challenges of such program, the requirement that the detector resolution is better that the neutrino mass by a factor 2 - 3, while at the same time dealing with extreme strong source strengths, appears to be the most difficult one to achieve. It essentially restricts the applicability of the discussed approach.
3) In the next few years a variety of approaches (KATRIN, cosmology & astrophysics, $0\nu\beta\beta$ decay) promise to reach sensitivity to $m_\nu \sim 0.2$ eV or even better. If one or all of these approaches find positive evidence, e.g.. if we can conclude that $m_\nu \geq 0.2$ eV, it would be certainly worthwhile, and perhaps even imperative, to pursue the indicated program vigorously.

Spares